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14. ABSTRACT

Finding ways to intercept illicit nuclear materials and weapons destined for the U.S. via the maritime transportation system is an exceedingly difficult task. The purpose of this project was to develop decision support algorithms that help to optimally intercept illicit materials and weapons. The algorithms developed focused on finding inspection schemes that minimize total cost, including the "cost" of false positives and false negatives.

The project viewed the inspection problem as a stream of entities arriving at a port, with a decision maker having to decide how to inspect them, which to subject to further inspection and which to allow to pass through with only minimal levels of inspection. Our approach involved decision logics and was built around problem formulations that led to the need for combinatorial optimization algorithms as well as methods from the theory of Boolean functions, queuing theory, and machine learning. Algorithms for designing port-of-entry inspection must consider a variety of practical complications, contributing to a combinatorial explosion caused by the many possible alternative inspection strategies. In this project, we developed approaches that bring many of these complications explicitly into the analysis, while still reducing the overall computing time.

15. SUBJECT TERMS
Port-of-entry inspection, container inspection, sequential decision making, binary decision tree, Boolean decision function.

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Final Report

DIMACS Project on Algorithms for Port of Entry Inspection

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Objectives and Approach

Finding ways to intercept illicit nuclear materials and weapons destined for the U.S. via the maritime transportation system is an exceedingly difficult task. Until recently, only about 2% of ships entering U.S. ports have had their cargoes inspected. The percentage at some ports has now risen to 6%, but this is still a very small percentage. The purpose of this project was to develop decision support algorithms that help to optimally intercept illicit materials and weapons. The algorithms developed focused on finding inspection schemes that minimize total cost, including the "cost" of false positives and false negatives.

The project viewed the inspection problem as a stream of entities arriving at a port, with a decision maker having to decide how to inspect them, which to subject to further inspection and which to allow to pass through with only minimal levels of inspection. This is a complex sequential decision making problem. Sequential decision making is an old subject, but one that has become increasingly important with the need for new models and algorithms as the traditional methods for making decisions sequentially do not scale. Previous algorithms for optimally intercepting illicit cargo assumed that sensor performance, operating characteristics of ports, and overall threat level were all fixed. The approach in this project involved decision logics and was built around problem formulations that led to the need for combinatorial optimization algorithms as well as methods from the theory of Boolean functions, queuing theory, and machine learning.

Practical complications that arise in container inspection include economic impacts of surveillance activities, errors and inconsistencies in available data on shipping and import terminal facilities, and the tradeoffs between combinations of sensors. A full-blown approach to the port-of-entry inspection problem must include the decision problem of when to initiate different levels of inspection if there are seasonal variations in cargo flows and cargo types, sensor reliability effects, and changing threat levels. In general terms, the inspection problem requires exploring new sensor deployment methods and sensor configurations, the problem of false alarms from naturally occurring radiation sources (which vary spatially) and from innocent cargos (such as medical waste), and models of "information sensors." Algorithms for designing port-of-entry inspection rapidly come up against the combinatorial explosion caused by the many possible alternative inspection strategies. In this project, we worked to develop an approach that brings many of these complications explicitly into the analysis.

The project was carried out in collaboration between a university team of faculty and students and a team from the Los Alamos National Laboratory. The university team was based at DIMACS (the Center for Discrete Mathematics and Theoretical Computer Science) and reflected the multi-disciplinary nature of the port-of-entry inspection problem with faculty and students from Mathematics, Operations Research (RUTCOR), Computer Science, Statistics, as well as Industrial and Systems Engineering, Civil & Environmental Engineering, School of Communication, Information & Library Studies, and Management Science & Information Systems, among others.

Technical Progress

The project began with a detailed review of the initial approach to the port-of-entry inspection problem taken by the Los Alamos team. Our Los Alamos partners described four tests currently in use for deciding if a cargo was positive, that is, contained illicit material. These tests (we will call them all sensors) were: 1) evaluation of ships' manifests; 2) passive radiation signature; 3) radiographic image; and 4) induced fission. Each of these tests or sensors has associated costs, including the cost of a reading indicating illicit material when there is none, a false positive (FP), the cost of a reading indicating there is no illicit material when there is, a false negative (FN), time costs of using the sensor, delay costs of waiting on line to be tested and waiting for the results, and fixed costs for equipment, labor, etc.

For each sensor the readings for cargo containing illicit material (positives) and readings for cargo not containing illicit material (negatives) are random variables. It is assumed that each is distributed normally and that the mean and standard deviation for each of these distributions is known. Setting a threshold level for when a reading is considered positive controls the performance characteristics of each sensor, that is the probability of FP and the probability of FN. For example, a false positive occurs when a reading from a sensor for a cargo that does not contain illicit material falls in the range where that sensor gives a positive reading. The model our Los Alamos partners created assigned an output of 0 (absence of illicit material) or 1 (presence of illicit material) for each sensor. In general, n sensors will yield a string (vector) of 0's and 1's of length n. A decision function is a Boolean function F on an n-dimensional vector with output 0 (negative) indicating the cargo is not suspected of containing illicit material and an output of 1 (positive) indicating the cargo is suspected and must be "unstuffed." The cost of a false positive is the cost of unstuffing, estimated at \$600. The cost of a false negative was based on the estimated cost of the destruction of the World Trade Center, \$50 billion, times the estimated fraction of imports with weapons of mass destruction (WMD), 1 per 5 years.

To which sensor a cargo is sent depends on the output of the previous sensor. This can be modeled with a binary decision tree (BDT), the nodes of which correspond to sensors, and branches of which correspond to the decision we make after learning the sensors' readings. Los Alamos researchers provided a complete enumeration of all possible binary decision trees built from no more than 4 sensors and corresponding to Boolean functions satisfying two assumptions: completeness (all variables are needed) and monotonicity (finding a more suspicious reading on any one sensor must not decrease the probability that the container itself should be inspected). They computed approximately optimal thresholds for each (one threshold per sensor) by a non-linear grid-search approach and then ranked the trees in terms of total "cost", including the cost of false positives and false negatives. However, their method cannot be

extended to more than four sensors, because of the combinatorial explosion of the number of binary decision trees. Restricting to complete and monotone Boolean functions, there are 114 possible functions and 11,808 possible binary decision trees. Using two months data from the LA Long Beach port, by exhaustive search, it was determined that there was 1 best, the best 100 fell into 10 patterns, and there were about 300 that were close enough to optimal.

In reality, we will want to use many more than four sensors and the large number of possible trees makes an exhaustive search infeasible. One goal of this project was to understand the characteristics and behaviors of the solution space with the ultimate objective of developing heuristics that allow rapid computation in finding optimal and near optimal trees. Such heuristics will eventually need to scale up to 12, 20, or even higher numbers of sensors.

There were clearly several shortcomings in the initial models. In particular, we recognized the need to model the many different types of costs involved in container inspection. There are fixed costs and salary costs for the inspection stations. There are delay costs that are primarily borne by the shippers. Also, a sufficiently long delay could cause the entire system to collapse causing proliferating economic costs throughout the country and the world. Moreover, the delays are not necessarily deterministic, but rather may be modeled as random variables to capture, for instance, the variability in the time to reach an inspection station.

The Rutgers team subdivided the project into four interdependent parts. One group studied the sensitivity of optimal and near optimal trees to the input parameters. By varying input parameters such as the costs of false positives and false negatives, the costs of delays, etc., this group examined sensitivity of solutions to changes in these parameters. This group also applied "tree space" techniques to study the dataset of 11,808 possible binary decision trees provided by LANL for the case of 4 sensors. A second group considered the optimization problem in the context of a shipping port and built a simulation model of inspection stations as one part of an operating port. Such a model allowed estimation of some of the cost parameters by, for example, providing estimates of delays. A third group developed new modeling approaches that are computationally cheap, highly scalable, and able to incorporate various cost factors with enough flexibility to include future technologies. A fourth group investigated the optimum threshold levels for sensors so as to minimize overall cost as well as minimize the probability of not detecting hazardous material.

In this port-of-entry inspection project, the team extended the earlier work at Los Alamos in various ways: doing sensitivity analysis on their results; making more restrictive assumptions about the nature of the binary decision trees; introducing a new and promising polyhedral approach; and broadening the class of binary decision trees considered in order to introduce more computationally efficient search procedures for optimal inspection strategies.

Experimental Sensitivity Analysis

As a stream of containers arrives at a port, a decision maker has to decide how to inspect them, which to subject to further inspection, which to allow to pass through with only minimal levels of inspection, etc. We viewed at this as a complex sequential decision making problem. Stroud and Saeger of Los Alamos formulated this problem, in an important special case, as a problem of

finding an optimal binary decision tree for an appropriate binary decision function. Rutgers project team members – Sakat Anand, David Madigan, Richard Mammone, Saumitr Pathak, and Fred Roberts – did an experimental analysis of the Stroud-Saeger method that led to the conclusion that the optimal inspection strategy is remarkably insensitive to variations in the parameters needed to apply the method. Anand, Madigan, Mammone, Pathak, and Roberts' work showed a remarkable robustness in the conclusions about optimal binary decision trees in sequential decision making algorithms in inspection applications. Very few trees arise as optimal over a wide range of choices of values for the key parameters in the model. Moreover, there is also considerable robustness in the optimal Boolean decision function – very few decision functions correspond to the optimal trees and those that do often are closely related. They do not yet have a good theoretical explanation for these conclusions about robustness. They also do not have a good understanding, as yet, of the relations between the different optimal trees, in particular their tree structure. These preliminary results are intriguing and suggest many additional questions.

Further analysis of the robustness of the second, third, and fourth-ranked trees also remains for study, though initial results show a great deal of robustness akin to that already discovered. In practical applications, with many uncertainties, a near-optimal tree might very well be a perfectly acceptable solution to the inspection problem. In this case, there might be more efficient methods for finding near-optimal trees than the brute force methods described by Stroud and Saeger and tested here. These approaches involved incrementing individual sensor thresholds in fixed-size steps in an exhaustive search for threshold values that minimize the expected cost of a binary decision tree.

More efficient algorithms recently developed by team members Madigan, Sushil Mittal and Roberts are able to avoid exhaustive search over a large number of threshold values for each sensor by using combinations of standard nonlinear search algorithms such as the Gradient Descent Method and Newton's Method. Moreover, by making less restrictive assumptions on the allowable trees than assuming that they come from complete, monotone Boolean functions, they achieved solutions much faster and were able to extend the methods to trees involving more than four types of sensors.

Simulation Modeling and Analysis of Cargo Flow

The binary decision tree is a model of the security operations of using various sensors to obtain readings of various types on cargo containers. These security operations take place in the context of a port in which there are many, many other activities that affect and are affected by the security operations. This part of the project focused on modeling and analysis of security operations for cargo flow through marine ports, with special emphasis on containerized cargo subject to the Container Security Initiative (CSI) program in the context of the entire port operation. Rutgers project members Tayfur Altiok and Benjamin Melamed built a prototype simulation model of cargo security operations in a container port including handling, storage and inspection. This initial simulation model was developed using the web-based ANYLOGIC simulation tool. The objective was to enable us to understand the efficiency of the security operations and their impact on various delays in a typical marine port. Vessel arrival processes, vessel-unloading operations and the various inspection processes were all critical components of the modeling. The impact of the arrival process and the inspection ratio on the overall marine

port operation was studied. The simulation model provided input into parameter ranges on costs and delays used in the sensitivity analysis described above. The simulation model also allows us to test the effectiveness of decision algorithms for cargo inspection in the context of the overall port operation.

A Model for Finding Optimal Inspection Strategies for Container Inspection

Liliya Fedzhora, Paul Kantor, and Endre Boros from Rutgers, and Phil Stroud and Kevin Saeger from Los Alamos extended the earlier work at Los Alamos and formulated a large-scale linear programming model yielding optimal strategies for container inspection. This model is based on a polyhedral description of all decision trees in the space of possible container inspection histories. The dimension of this space, while quite large, is an order of magnitude smaller than the number of decision trees. This formulation allows incorporating both the problem of finding optimal decision trees and optimal threshold selection for each sensor into a single linear programming problem. The model can also accommodate budget limits, capacities, etc., and be solved to maximize the achievable detection rate. Fedzhora, Kantor, Boros, Stroud, and Saeger have built an experimental code for this model in AMPL (using the CPLEX solver), and also in MOSEL (using the XPRESSMP solver). The team solved this model for 4 sensors, and branching that allows up to 7 possibly different routing decisions at each sensor (in contrast to the binary routing in the earlier Los Alamos model, and implicit in Boolean models) in a few minutes of CPU time, on a standard desktop PC. The model is able to run for as many as 7 sensors when only binary decisions are allowed. Initial computational results showed that 5-7 thresholds already give very good results.

The new mathematical method behind this model is a higher dimensional polyhedral characterization of decision trees. This model, though its size increases exponentially with the number of sensors, is still more efficient by a large exponential factor than the enumeration based approach originally proposed by the Los Alamos team. This allows solution of the more complicated problem for up to 6-8 sensors.

An interesting outcome from the initial computations is the observation that the best inspection strategy is NOT a single decision tree, but rather a mixture of several decision trees. Such a mixed strategy not only provides better performance (higher detection rate at a lower cost), but it is also safer in practical situations, since it is much harder to adapt "malicious packing strategies" to it.

Thus, the team's results demonstrate that (1) allowing multiple sensor thresholds allows substantial improvement with no added cost; and (2) optimal strategies, in fact, involve a convex mixture of several decision trees rather than a single best tree.

Sensor Thresholds in Port-of-Entry Inspection Systems

Seaports are critical gateways for the movement of international commerce. More than 95 percent of our non–North American foreign trade arrives by ship. With "just-in-time" deliveries of goods, the expeditious flow of commerce through these ports is essential. Containers are inspected in order to detect the smuggling of nuclear materials, hazardous and illegal shipments.

Slowing the flow long enough to inspect either all or a statistically significant random selection of imports would be economically intolerable. There are only two techniques of non-invasively "seeing" into a container, both involving projection and the resultant transmission or reflection of waves: 1) Electromagnetic (EM) waves (radio waves, light, x-rays, gamma rays, etc.) and 2) Material vibration waves (ultrasound). A variety of means exist for converting these waves into images suitable for human inspectors to interpret. The interpretation may lead to accepting a container that contains undesirable material (false negative) or may lead to further inspection of a container that is acceptable (false positive) which results in delays and added cost. Clearly, the threshold levels of these techniques have a direct effect on these types of errors and the inspection selection.

Rutgers team members – Hao Zhang, Christina Schroepfer, and Elsayed A. Elsayed – developed an approach for determining the optimum threshold levels of the sensors at inspection stations in order to minimize the overall cost of inspection and the probability of accepting a suspicious container. Their approach also determined the optimum sequence of the inspection stations. Methods for estimating the probabilities of false negative and false positive were developed for two commonly used inspection systems: series and parallel. The approach is general and it requires prior knowledge of "misclassifications" as a function of the sensors' threshold levels. The optimization approach searches within discrete values of the threshold levels to determine the levels that minimize the overall cost of inspection. Zhang, Schroepfer, and Elsayed decomposed the port-of-entry inspection problem into two sub-problems. The first problem deals with the determination of the optimum sequence of inspection or the structure of the inspection decision tree in order to achieve the minimum expected inspection cost. The second problem deals with the determination of the optimum thresholds of the sensors at inspection stations so as to minimize the cost associated with false positive (false alarm, which results in additional manual inspection) and false negative (failure to identify illicit materials or weapons). The first problem can be formulated and investigated using approaches parallel to those used in the optimal sequential inspection procedure for reliability systems as described by previous researchers in this field. After the sequences of inspection and the structure of the inspection decision tree are determined, Zhang, Schroepfer, and Elsayed determined the optimum thresholds of the sensors at inspection stations.

Software and Hardware Prototypes

A prototype simulation model of cargo security operations in a container port including handling, storage and inspection was developed using the web-based ANYLOGIC simulation tool.

Papers

T. Altiok and B. Melamed, "Modeling of the Container Inspection Process at Marine Ports," in preparation.

T. Altiok and D. Jagerman, "Modeling Vessel Arrivals in Marine Ports," in preparation.

S. Anand, D. Madigan, R. Mammone, S. Pathak, and F. Roberts, "Experimental Analysis of Sequential Decision Making Algorithms for Port of Entry Inspection Procedures," in *Proceedings of the International Conference on Intelligence and Security Informatics*, 2006.

E. Boros, E. Elsayed, P, Kantor, F. Roberts, and M. Xie, "Optimization problems for port-of-entry detection systems", submitted.

E. Boros, L. Fedzhora, P. Kantor, K. Saeger, and P. Stroud, "Large Scale Linear Programming Model for Finding Optimal Container Inspection Strategies," in preparation.

E.A. Elsayed, "Reliability Prediction and Accelerated Testing," to appear in *Complex System Maintenance Handbook*, edited by: K.A.H. Kobbacy and D.N.P. Murthy, Springer-Verlag, forthcoming 2007.

E.A. Elsayed and H. Zhang, "Design of Optimum Simple Step-Stress Accelerated Life Testing Plans," to appear in *Recent Advancement of Stochastic Operations Research*, edited by S. Osaki, T. Dohi and K. Sawaki, World Scientific, Singapore, forthcoming 2007.

D. Madigan, S. Mittal, and F. Roberts, "Sequential Decision Making Algorithms for Port of Entry Inspection: Overcoming Computational Challenge," to appear in *Proceedings of the International Conference on Intelligence and Security Informatics*, 2007.

F. Roberts, "Decision Support Algorithms for Port-of-Entry Inspection," in *Working Together: Research & Development Partnerships in Homeland Security, Proceedings of DHS/IEEE Conference*, Boston, 2005

F. Roberts, "Laboratory for Port Security," *New Jersey Regional Homeland Security Technology Committee*, April 12, 2006.

H. Zhang, C. Schroepfer, and E.A. Elsayed, "Sensors Threshold in Port-of-Entry Inspection Systems," in *Proceedings of the 12th ISSAT International Conference on Reliability and Quality in Design*, Chicago, Illinois, USA, August 3-5, 2006.

Talks

Members of this project organized a focused session at the Institute for Operations Research and the Management Sciences (INFORMS) annual meeting, November 13 – 16, 2005 that featured four talks from this project. The titles, authors and abstracts of the talks presented in that session are:

- *"Data Mining Complex Sensor Simulations for Optimal Security"*

Paul B. Kantor, School of Communication, Information and Library Studies, Rutgers University
Alexander Kogan, Department of Accounting & Information Systems, Rutgers University
Brenda Latka, DIMACS, Rutgers University
Richard Mammone, Center for Advanced Information Processing, Rutgers University
Phillip Stroud, Los Alamos National Laboratory

Rigorous calculation of screening schemes produces a rich database with over 10,000 instances of parameters settings and expected performance levels. These are mined to extract heuristic

relations that will be useful when the number of sensors makes direct exploration computationally intractable.

- *"Decision Support Algorithms for Port-of-Entry Inspection"*

Fred S. Roberts, DIMACS, Rutgers University
Phillip Stroud, Los Alamos National Laboratory

We describe approaches to efficiently discover smuggling attempts at U.S. ports of entry. We use a sequential decision making model: Containers are routed to different tests depending on outcomes of earlier tests. We describe ways to find inspection schemes minimizing cost, including "cost" of false positives and negatives.

- *"Modeling Cargo Flow Security Operations in Marine Ports"*

Tayfur Altiok, Industrial and Systems Engineering, Rutgers University
Kevin Saeger, Los Alamos National Laboratory
Benjamin Melamed, Rutgers Business School, Rutgers University

We model cargo security operations in a container port including handling, storage and inspection. Here, vessel arrival processes, vessel unloading operations and the inspection process are critical modeling components. The impact of the arrival process and the inspection ratio on the overall marine port operation will be discussed.

- *"Optimum Inspection Strategies for Port Entry Containers"*

Endre Boros, Rutgers Center for Operations Research, Rutgers University
E. A. Elsayed, Industrial and Systems Engineering, Rutgers University
Liliya Fedzhora, Rutgers Center for Operations Research, Rutgers University
Hao Zang, Industrial and Systems Engineering, Rutgers University

We develop a network optimization type linear programming model for sequential container inspection. In this model we minimize the total "cost," including expenses arising from storage, inspection and delays, as well as the estimated cost incurred by false positives and negatives.

Additional talks related to this project include:

Tayfur Altiok and David Jagerman, "Vessel Arrivals and Queueing in Marine Ports," *Institute for Operations Research and the Management Sciences (INFORMS) Annual Meeting*, San Francisco, Nov 13-16, 2005. (Invited).

Tayfur Altiok and David Jagerman, "Analysis of the Vessel Arrival Process," Harbour, *Maritime and Multimodal Logistics Modeling and Simulation Conference*, Marsailles, France, October, 2005.

Sakat Anand, David Madigan, Richard Mammone, Saumitr Pathak, and Fred Roberts, "Experimental Analysis of Sequential Decision Making Algorithms for Port of Entry Inspection Procedures," *IEEE International Conference on Intelligence and Security Informatics (ISI-2006)*, San Diego, May 23-24, 2006.

Endre Boros (joint research with L. Fedzhora, P.B. Kantor, K. Saeger and P. Stroud), "Large Scale LP Models for Finding Optimal Container Inspection Strategies," *Risk Symposium 2006: Risk Analysis for Homeland Security and Defense: Theory and Application*, Santa Fe, NM, March 20-22, 2006.

Endre Boros, "Large Scale Linear Programming Applications," *EURO 2006 Meeting*, Reykjavik, Iceland, July 2-5, 2006.

Endre Boros, "Optimization Models for Container Inspection," *Seventh New Jersey Universities Homeland Security Research Consortium Symposium*, November, 2006.

Fred S. Roberts, "Algorithms for Port of Entry Inspection for WMDs," *Conference on Mathematical Methods in Counter-terrorism*, Columbia, SC, November, 2005.

Fred S. Roberts, "Decision Support Algorithms for Port-of-Entry Inspection", DHS Meeting on Research and Development Partnerships in Homeland Security, Boston, April 2005. http://www.dimacs.rutgers.edu/People/Staff/froberts/DHSBostonPorts4-19-05rev.ppt

Other Conference Activity

In May 2007, Rutgers will host the Fifth IEEE International Conference on Intelligence and Security Informatics and, motivated by this project, Port Security will be the major theme. This conference aims to support the development and growth of a homeland-security epistemic community by providing a forum and podium for diverse communities from academia, business and government with interest in homeland security. Members of this project are serving as Conference Co-Chairs (Paul Kantor and Fred Roberts) and Program Co-Chairs (Tayfur Altiok and Benjamin Melamed).

Interaction with DoD, Government Agencies and Industry

Los Alamos: This project involved close interaction with research partners at Los Alamos. In addition, DIMACS project team members participated in the March 2006 Risk Symposium sponsored by Los Alamos National Laboratory (LANL), where the theme was Risk Analysis for Homeland Security and Defense. The group contributed new ideas on large-scale linear programming methods for finding optimal container inspection strategies. Following the Symposium, the Rutgers and LANL teams met at Los Alamos to discuss research directions for future collaborations.

Laboratory for Port Security: One of the outcomes of this project was the establishment of the DIMACS – CAIT Laboratory for Port Security. (CAIT is the Center for Advanced Infrastructure and Transportation at Rutgers.) The DIMACS-CAIT Laboratory for Port Security (LPS) was established in 2006 by a Rutgers University Academic Excellence Fund grant to carry out collaborative research on marine/land port security, as well as the security of surrounding transportation infrastructure and coastal waters. LPS addresses key issues relevant to marine/land container inspection operations and technology, bridge/tunnel security operations,

coastal interdiction, and preparedness for and recovery from high-consequence events. The LPS research scope includes the analysis of relevant technological approaches (wireless networks, RFID, image processing, HF radar) and modeling and evaluation of field operations and risk (mathematical and simulation).

Through the LPS, project team members have met with representatives from industry, the DHS, and state and local agencies, including:

George T. Garrett, Deputy Assistant Director, *New Jersey Office of Homeland Security*
Kathleen M. Haage-Gaynor, Area Director, *Newark / New York U.S. Customs and Border Protection, Department of Homeland Security*
James McElwain, Deputy Director, *New Jersey Office of Homeland Security and Preparedness*
Jeffrey J. Milstein, Operations Manager, *Moran Shipping Agency*
Harold W. Neil Jr., Director, Transportation Security, *New Jersey Department of Transportation*
John P. Paczkowski, Director, Operations and Emergency Management, *Port Authority of New York and New Jersey*
David L. Scott, Commander, *United States Coast Guard, Delaware Bay Sector*.

Each of these leaders in the field is now on the LPS Advisory Board, where they provide practical insights and rich experience to the project team. By interacting with these government agencies and industry leaders, project members are both finding more practical applications for their methods and learning practical restrictions that they are incorporating into their models.

LPS has involved the team with *DHS Customs and Border Protection*, the *US Coast Guard*, and the *NJ Office of Homeland Security and Preparedness* (OHSP), and in particular, in helping to develop port security training materials. LPS has also involved the team with the *Port Authority of New York/New Jersey* and with several private marine terminal operators.

Project team members visited the Coast Guard Delaware Bay Sector Headquarters in Philadelphia on June 19, 2006, at the invitation of the Captain of Port. The group received briefings on port security problems and took a tour of the Port of Philadelphia on a Coast Guard vessel. The tour included a container port, hazardous LNG and butane facilities along the waterfront, a view of Port infrastructure, and an introduction to port security issues. The project team also visited the Port of Elizabeth, NJ on December 6, 2006, and was escorted by a Customs and Border Protection team for a behind the scenes visit to the container terminal. This included visits to the Maher and Port Newark Container Terminals and provided a first-hand view of the mobile VACIS machines that are used to test cargo for contraband and weapons. Project members are in the process of developing joint projects with the Coast Guard Delaware Bay Sector as well as with the New Jersey Office of Homeland Security and Preparedness, some of whose leaders are advisors to the Lab for Port Security.

Project faculty participant, Tayfur Altiok, is now serving as a member of the Area Maritime Security Committee's Training and Exercise Subcommittee. This is the committee that determines risks and vulnerabilities in Sectors New York and Philadelphia.

The project hosted a November 13-14, 2006 visit by Richard Hoshino of the *Canada Border Services Agency* (CBSA) in which he delivered a talk on mathematical techniques that the CBSA applies in container inspection, and subsequent discussions identified numerous areas for future interaction. Hoshino has since made a proposal to his management for them to adopt some of our methods in their container security inspection protocols and to provide us with data so that we can collaborate further.

Current Students and Recent Graduates Supported by ONR

From the beginning, many graduate students have had major involvement in this project. This involvement informed their research and may impact the direction of their future careers. The students who have participated in this project are:

Ozlim Akpinar, Rutgers University, Industrial and Systems Engineering, graduate student
Saket Anand, Rutgers University, Electrical & Computer Engineering, graduate student
Liliya Fedzhora, Rutgers University, Rutgers Center for Operations Research graduate student
Abdullah Karaman, Rutgers University, Industrial and Systems Engineering graduate student
Devdatt Lad, Rutgers University, Electrical & Computer Engineering, graduate student
Mingyu Li, Rutgers University, Statistics, graduate student
Francesco Longo, University of Calabria, Italy, visiting graduate student
Martin Milanic, Rutgers University, Rutgers Center for Operations Research, graduate student
Sushil Mittal, Rutgers University, Electrical & Computer Engineering graduate student
Saumitr Pathek, Rutgers University, Electrical & Computer Engineering graduate student
Paul Raff, Rutgers University, Mathematics, graduate student
Christina Schroepfer, Rutgers University, Industrial and Systems Engineering, graduate student
Hao Zhang, Rutgers University, Industrial and Systems Engineering, graduate student
Yada Zhu, Rutgers University, Industrial and Systems Engineering, graduate student

Undergraduate Outreach

Faculty participants in this project have served as mentors in the DIMACS Research Experience for Undergraduates (REU) program, introducing undergraduates to some of the research issues and problems involved in port security and generating interest in homeland security problems among the next generation of researchers.

Other Educational Outreach

Algorithms for port-of-entry inspection will be among the topics presented to high school teachers in a DIMACS workshop on the Mathematics of Homeland Security to be held in May 2007. The workshop will enable participating teachers to introduce their students to ways in which mathematics can be applied address problems in homeland security, such as container inspection. In particular, Fred Roberts will present the topic of algorithms for port of entry container inspection in a two-hour lecture and "workshop" for the teachers.

Comment on Other Funding

The "seed" money from this modest ONR grant helped us expand the project under an NSF grant and also to get Rutgers University to provide funds under its Academic Excellence program. The results described here are the product of both ONR and NSF funding, which we combined in support of this effort. Portions of this work are continuing under a new ONR grant on "Optimization Problems for Detection Systems" (ONR N00014-07-1-0299), which continues until 2010.

DIMACS

Center for
Discrete Mathematics
& Theoretical Computer Science

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May 29, 2007

Defense Technical Information Center
8725 John J. Kingman Road
STE 0944
Fort Belvoir, VA 22060-6218

Dear Sir/Madam:

Enclosed please find the final report for ONR award # N00014-05-1-0237, Algorithms for Port-of-Entry Inspection. Please let me know if you need anything else.

Sincerely,

Fred S. Roberts